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The Effect of Soil Moisture and Fertilizers on Seed Germination

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THE EFFECT OF SOIL MOISTURE AND FERTILIZERS ON SEED GERMINATION

by

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Stephen Dubetz

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INTRODUCTION

Failure of viable seeds to germinate results in poor stands and often in lower yields. Some of the more important factors that affect germination of seed are temperature, moisture, aeration, and alkalinity.

Planting of specialty crops under irrigation in southern Alberta, Canada, usually is done when temperature is favourable to germination. However, soil moisture, especially in the seed zone, may not always be adequate - a situation brought about, in part, by the strong winds that prevail in this area. Results at the Experimental Farm, Lethbridge, Alberta, show that irrigated crops respond to phosphorus and nitrogen. During the past six years there have been substantial increases in the amounts of nitrogen fertilizers used. The commercial drills used in this area place the fertilizer in partial contact with the seed. Preliminary results have shown that high rates of nitrogen fertilizer, when applied with the seed, decreased the germination of sugar beets, corn, and beans when the soil moisture appeared to be low.

In the work reported herein, the germination of these three crops was studied under various moisture and fertilizer treatments. In addition, sugar beet seeds were germinated in iso-osmotic concentrations of ammonium nitrate and mannitol to determine if nitrogen was detrimental to germi-

nation.

The work was carried out at the Experimental Farm, Lethbridge, in 1957.

LITERATURE REVIEW

To understand the effects of moisture and fertilizers on germination, it is necessary to define certain moisture and osmotic pressure concepts as related to the germinating medium, that is, the soil.

Soil moisture and soil moisture tension

Soil moisture is a physical property of the soil, which is commonly determined on a gravimetric basis and expressed as a percentage of the oven-dry weight of the soil. Briggs and McLane (1907) and Briggs and Shantz (1912) developed the moisture equivalent and wilting coefficient constants, which approximated the upper and lower limits of the available soil moisture. It remained for Veihmeyer and Hendrickson (1949) to define the constants more accurately and to state that field capacity less the permanent wilting percentage is the amount of soil moisture available to plants. The permanent wilting percentage of a soil, as defined by Hendrickson and Veihmeyer (1945) who used dwarf sunflowers as the test plants, is that moisture content of a soil at which plants wilt and do not recover in an approximately saturated atmosphere. Other methods for determining the permanent wilting percentage are those described by Breazeale and McGeorge (1949) and Lehane and Staple (1951). The field capacity of a soil may be defined as the moisture retained in a soil after a rainfall or irrigation, allowing 48 hours for the

excess water to drain off or percolate through the soil.

The gravimetric methods for determining the above moisture constants are relatively slow and laborious. By employing a pressure membrane apparatus, Richards and Weaver (1944) were able to express moisture availability in terms of atmospheres of tension. Soil moisture tensions of 15 atmospheres and 1/3 atmosphere correspond to the permanent wilting percentage and field capacity, respectively, for most soils. Although all the above-mentioned constants are somewhat arbitrary, nevertheless they are very convenient and useful. By preparing soil moisture characteristic curves for specific soils, gravimetric values can be readily converted to atmospheres of tension, and, conversely, moisture tension can be expressed as percentage of moisture.

Total soil moisture stress

The sum of soil moisture tension and osmotic pressure forces is called the total soil moisture stress. Both forces can be expressed in terms of atmospheres of pressure, so that their additive effect on the availability of moisture to plant growth, theoretically, could be measured.

The total soil moisture stress of a soil is determined by the freezing point depression method. Bouyoucos (1915), Parker (1921), and Pinckney (1924) carried out many early investigations on the freezing point depression of soils and inert materials before the present-day concepts of soil moisture were known. These workers used the Beckman thermometer to observe the temperature readings. The substitution of a sensitive thermocouple for the Beckman thermometer

by Bodman and Day (1937) resulted in greater accuracy and improvement of technique. Richards and Campbell (1948) introduced the thermistor method by which resistance rather than potential readings were made.

Osmotic pressure

Every student of biology is familiar with the phenomena of osmosis, which can be defined as the diffusion of a solvent across a differentially permeable membrane from a region of its greater diffusion pressure to a region of its lower diffusion pressure. Osmotic pressure is a rating of the potential maximum pressure that can be developed as a result of osmosis. By virtue of the anions, cations, molecules, and micelles in soil water, soil solutions exhibit the property of osmotic pressure. In the case of saline soils, the osmotic effect would be appreciably greater than in normal soils. Dissolved salts, whether derived from natural sources as in saline soils or from fertilizers, impair the availability of water to plants by increasing the osmotic pressure of the soil solution.

Osmotic pressure can be measured indirectly by difference, that is, by subtracting soil moisture tension from the total soil moisture stress.

Germination as affected by soil moisture

Meyer and Anderson (1952) state that the initial step in germination is the imbibition of water by the various tissues within the seed. This enables the embryo to break through the softened seed coat and renders the seed coat more permeable to gases, so that respiration can proceed.

The water also acts as the solvent for the translocation of food in the germinating seed. Stiles (1948) made a quantitative study of the course of water absorption by seeds during germination and found that seeds differ in total and rate of water uptake; germination varied with varieties; and seed coats of different seeds had different absorption capacities.

Peters (1920) attempted to answer the question as to whether seeds can germinate when the amount of soil moisture is so low that plants growing in it wilt and die. He showed that seeds of peas, soybeans, corn, and wheat germinated at or below the wilting coefficient of 1.31 per cent moisture in quartz sand of 0.1 mm. size. Doneen and MacGillivary (1943) made an extensive study of the effect of soil moisture on seed germination. Their results can be summarized as follows:

1. Seed germination was progressively delayed as the initial soil moisture percentage was decreased.

2. The germination percentage of some crops was lowered as the soil moisture was decreased toward the wilting percentage, but with some crops the proportion of seeds germinating was not influenced as long as the soil moisture was above the wilting percentage.

3. Several of the crops appeared to germinate at moisture percentages slightly below the reported wilting percentage.

Working with sugar beets, Hunter and Dexter (1950) reported that, in a Brookston clay loam, germination did not

occur unless the seed took up somewhat over 30 per cent of moisture. Hunter and Erickson (1952) showed that, in order for seeds to germinate, each species had to obtain a specific moisture content. The minimum moisture content, reported by them, was 30.5 per cent for corn, 26.5 per cent for rice, 50.0 per cent for soybeans, and 31.0 per cent for sugar beets. The authors established that at 25°C. corn, rice, soybeans, and sugar beets should have a moisture tension of not more than 12.5, 7.9, 6.6, and 3.5 atmospheres, respectively, to germinate.

Uhvits (1946) studied the effect of NaCl and mannitol on the germination of alfalfa seed and reported that the rate and percentage of seeds germinating were decreased by the use of increasing osmotic pressure. She also found that there was greater injury to seedlings in NaCl solutions than in mannitol solutions at equal osmotic concentrations, suggesting a toxic effect of NaCl. In reviewing her work, Ayers (1952) attributed the injury to toxic amounts of chloride.

Ayers and Hayward (1948) found that beans and sugar beets were more sensitive during germination than barley. Results from the U. S. Salinity Laboratory Staff (1954) showed that beans, sugar beets, alfalfa, and barley failed to germinate when the conductivity of the saturation extract was higher than approximately 6, 6½, 10½, and 18 millimhos per cm., respectively.

Coe (1923) demonstrated that large applications of mineral fertilizers may retard, reduce, or inhibit the

germination of crops. Maxton (1927) concluded that the deleterious effect of fertilizers seemed to be in their preventing germination of seeds, and Gaywala (1933) found that failure of germination occurred only when the fertilizer came in concentrated and close contact with the seed.

Stout and Tolman (1940) reported that ammonia released from nitrogenous compounds of seed ball extracts by enzymatic hydrolysis inhibited the germination of sugar beets. Lugo (1955) studied the effect of nitrogen on the germination of vanilla. Evidently, vanilla seeds are difficult to germinate, so he used a special germinating medium known as Knudson's Solution B. By varying the concentrations of the various nutrients in the culture, he found that only nitrogen affected germination. He showed definite proof of the inhibiting action of nitrogen on the germination of vanilla seeds and that the nitrate ion was more retarding than the ammonium ion. In view of the results of the last two references, the inhibiting action of nitrogen on germination cannot be overlooked.

METHOD OF PROCEDURE

This study was divided into two phases as follows:

1. Germination studies in the greenhouse involving three crops, three moisture levels, and five fertilizer treatments. The crops were germinated in a soil medium.

2. Studies in a germination cabinet involving seed from the same three crops planted in sand, which was sub-irrigated with solutions at various osmotic pressures.

The species used in the study were canning corn (Zea Mays), field beans (Phaseolus vulgaris), and sugar beets (Beta vulgaris). The same varieties and the same source of seed were used throughout. The variety of corn was Seneca Golden; of beans, Michelite; and of sugar beets, decorticated Kuhn.

Standard germination tests were carried out on seed samples of the three crops by the Plant Products Division of the Canada Department of Agriculture Production Service at Calgary, Alberta. The results of the standard germination tests appear in the Appendix.

Germination studies in the greenhouse

The soil used in this experiment was taken from an area which primarily had grown vegetable crops and which had had neither barnyard manure nor commercial fertilizer added to it during the previous 15 years. The top 3 inches of soil were stripped from the field, dried, thoroughly mixed, and

screened. Subsamples of soil used for moisture determinations were passed through a 2-mm. sieve.

The percentage moisture (Pw)[1] at field capacity as determined by the method of Lehane and Staple (1953) was found to be 22.4 per cent. The Pw at the permanent wilting percentage was 8.2 per cent as determined by Lehane and Staple (1951). The amount of water available to plants, as determined on disturbed soil samples, was thence found to be 14.2 per cent. By means of a pressure membrane apparatus, moisture determinations were made at several tensions. The moisture data for this soil were used to prepare the moisture release curve as shown in Figure 1.

The following three moisture levels were used:

1. Soil at 1/4 of the available moisture (Pw = 11.75).
2. Soil at 1/2 of the available moisture (Pw = 15.30).
3. Soil at 3/4 of the available moisture (Pw = 18.85).

Immediately prior to the preparation of the soil at the various moisture levels, the Pw of the air-dry soil was determined. The appropriate amounts of water necessary to prepare the soils were then calculated and the soils prepared. In the preparation of a soil all of the water was carefully sprinkled over half of the weighed soil. After thorough mixing, the remaining soil was added and the entire

1. Hereafter in this paper where Pw is used it will refer to the percentage moisture of the soil expressed on an oven-dry basis.

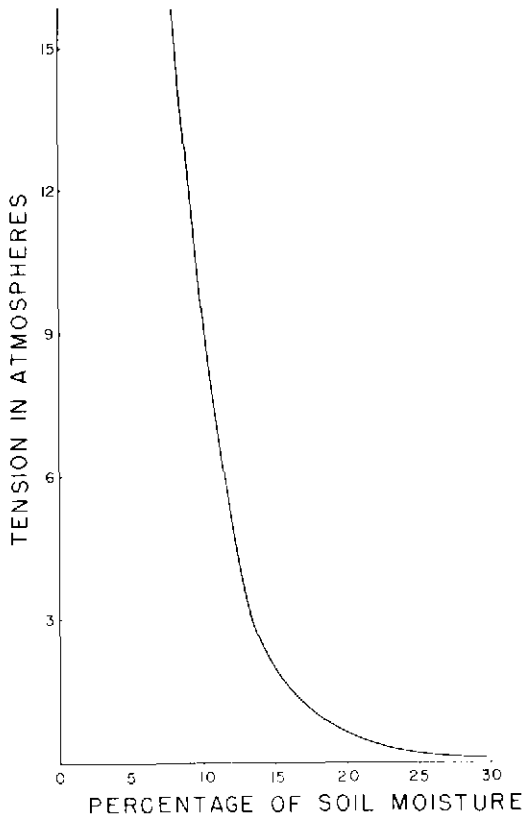

Figure 1. Soil moisture characteristic curve of loam soil, which was used in the experiment, Lethbridge, Alberta, 1957

mass was again mixed. The soil was left in cans, sealed with plastic to prevent moisture loss, for a period of a week to allow the moisture to come to equilibrium.

The following five fertilizer treatments were used:

1. Check - no fertilizer.
2. 50 lb. per acre P_2O_5.
3. 50 lb. per acre P_2O_5 plus 25 lb. per acre N.
4. 50 lb. per acre P_2O_5 plus 50 lb. per acre N.
5. Mannitol at molarity equal to treatment 3.

The sources of fertilizer were triple superphosphate (0-46-0) and ammonium nitrate (33.5-0-0). Treatment 5 was calculated on the assumption that the molecular weight of 0-46-0 fertilizer was 260. The mannitol treatment was included to check for the possibility of toxicity of the fertilizers.

Since virtually all the row crops in southern Alberta are grown in rows spaced 22 inches apart, the fertilizer requirements were calculated for this spacing although the rows in the experiment were only 2 inches apart. To confine the experimental area on a practical basis, it was assumed that the rows spaced 2 inches apart would be satisfactory, and that the fertilizer in a particular row would not influence the germination of an adjacent row.

The experiment was carried out in enamel developing trays. Each tray represented a moisture treatment for a particular crop, with the five fertilizer treatments randomized within it. The quadruplicate replicates were confined in blocks for each of the three crops. This split-plot

randomized block design would permit statistical reduction of the data by the analysis of variance method, for moisture, fertilizers, and the moisture x fertilizer interaction, for an individual crop.

The trays were first filled with 2 inches of soil. The fertilizers were then spread uniformly in the rows and the seed was placed on top of the fertilizer. All seeds were placed at 3/4-inch centres within the rows. Figure 2 illustrates the technique used in applying the fertilizers and in spacing the rows. The master form board was used for all trays and facilitated their preparation. Figure 3 shows the fertilizer and seed in a prepared tray just prior to being covered with soil. Approximately one inch of soil was placed over the seeds. To maintain uniformity in the trays, the amounts of soil to be used were measured by weight.

The trays were covered with plastic (2 mill polythene) and sealed with adhesive tape to prevent evaporation. The temperature in the greenhouse was kept relatively constant at 70°F.

Germination counts were taken as warranted during a 15-day period. The trays were uncovered, counts taken, and emerged seedlings removed. At the end of the 15-day period, all seeds that had healthy radicles 5 mm. or longer were considered germinated.

Freezing point depression determinations of soils. An attempt was made to determine the freezing point depressions of soil samples containing the different fertilizer and moisture treatments. The thermistor method of Richards and

Figure 2. Fertilizer treatments placed on spacing form prior to being pushed through the slots on to the soil of the tray, Lethbridge, Alberta, 1957

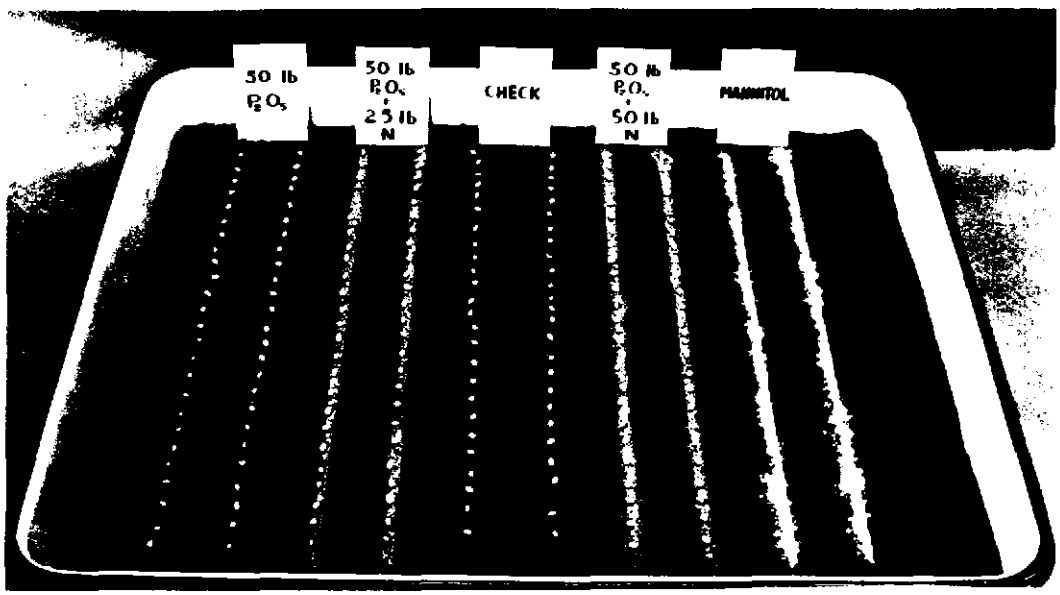

Figure 3. Germination tray with fertilizer treatments and bean seeds in place prior to being covered with soil and sealed with plastic sheeting, Lethbridge, Alberta, 1957

Campbell (1948) was used at the Utah State University in 1956, where the necessary apparatus and facilities were available.

Freezing point depression determinations were also attempted at Lethbridge using the same soil and treatments, except that the Heidenhain thermometer instead of the thermistor method was used.

Studies in the germination cabinet

Solutions were prepared at various concentrations whose osmotic pressures were equivalent to the total soil moisture stress of a soil. Since soil moisture tension does not play a part in solutions, reference to osmotic pressures of solutions is tantamount to saying the total moisture stress of the solutions. Iso-osmotic solutions of ammonium nitrate and mannitol were used. This phase of the study would provide germination limits for the three crops at the various osmotic pressures and would accurately assess the probability of nitrogen toxicity to germination.

Germination studies were carried out on cleaned sand in small sub-irrigated petri dishes, as described by Rayment (1956). The petri dishes were 20 mm. deep by 100 mm. in diameter. Each dish had a glass tube drain of 2 mm. inside bore fused to the bottom. Six-ounce dispensing bottles were used as reservoirs for the solutions. The dishes and bottles were assembled with rubber stoppers as illustrated in Figure 4. A glass tube leading from each bottle through the stopper to the outside provided for irrigation by expiration.

Figure 4. Apparatus used for germination in sand substrate with solutions of varying osmotic pressures, Lethbridge, Alberta, 1957. The petri dish contains the sand, the dispensing bottle the solution, and the glass side-arm permitted sub-irrigation of the sand with the solution.

The substrate used was Ottawa white sand, which was passed through a one-mm. screen and washed in hydrochloric acid. Washings were continued with distilled water until the pH of the filtrate was that of the distilled water. The sand was then dried in an oven at 105°C. and stored until used.

In preparing the required solutions the following procedure was used. A graph was plotted for the two chemicals with concentration in molality on the abscissa and osmotic pressure in atmospheres on the ordinate. International Critical Tables were used for obtaining freezing point depressions for the different molal concentrations. Osmotic pressures were then calculated directly using the formula O.P. = 12.06Δ, where O.P. = osmotic pressure and Δ is the freezing point depression.

Density data for ammonium nitrate solutions were obtained from International Critical Tables for converting the molal to molar concentrations. Density data for mannitol solutions were obtained by the author through the use of pycnometers, and similar concentration conversions were made. The molar concentrations were then plotted on the same graph. Although freezing point depression or osmotic pressure data are always calculated from molality, the conversion of concentration in terms of molarity greatly facilitated the preparation of solutions as direct volumetric dilution was then possible. The details of this procedure appear in the Appendix.

The drain hole in the petri dish was first covered with glass wool. The dish was then half-filled with washed sand over which a No. 40 ashless filter paper was placed. Twenty-five seeds were then scattered over the filter paper, another sheet of filter paper was placed over the seed, and the dish filled with more sand. Placing the seed between the filter paper facilitated counting the germinated seed. Four replicates of each species were used. The assembled dishes were placed in a germination cabinet in which the temperature was kept constant at 20°C.

The osmotic pressures of the solutions ranged from 2 to 10 atmospheres for beans and sugar beets and from 6 to 14 atmospheres for corn. The treatment interval varied by 2 atmospheres for each crop. The dishes were irrigated twice daily for 7 days, at the end of which time the germination counts were taken.

Statistical treatment

The statistical calculation was made on angular transformations of the percentage data. The inverse-sine transformations of Fisher and Yates (1953) were used. The percentage values of 0 were arbitrarily replaced by $1/4n$, where n is number of replicates. When a percentage value of 0 occurred repeatedly under a given treatment, as with some of the greenhouse data, that portion of the data was withdrawn from the statistical analysis. For this reason, complex analysis of variance computations, combining either moisture levels within a crop or inter-crop interactions, was not practical.

RESULTS

Germination studies in the greenhouse

Figures 5, 6, and 7 show the germination, under the various fertilizer and moisture treatments, for canning corn, field beans, and sugar beets, respectively. Tables 1, 2, and 3 show the mean percentages of germination for the comparable crops and treatments and the significant differences between the means as determined from Duncan's (1955) new multiple range test. Summaries of the analyses of variance appear in the Appendix. Since statistical significance was established at the one per cent level for the appropriate calculations, references to significant differences in the discussion will imply that these are highly significant differences.

Canning corn. When the Pw of the soil was 18.85, there were no significant differences in the percentage of germination of canning corn between the check, 50 lb. P_2O_5, mannitol, and 50 lb. P_2O_5 plus 25 lb. N treatments. The germination from the 50 lb. P_2O_5 plus 50 lb. N treatment was significantly lower than that from the other treatments.

Decreasing the soil moisture to 15.30 per cent resulted in germination from the 50 lb. P_2O_5 plus 25 lb. N treatment being significantly lower than the germination from the check, 50 lb. P_2O_5, and mannitol treatments. However, the germination from this treatment was significantly higher than that from the treatment that received an additional

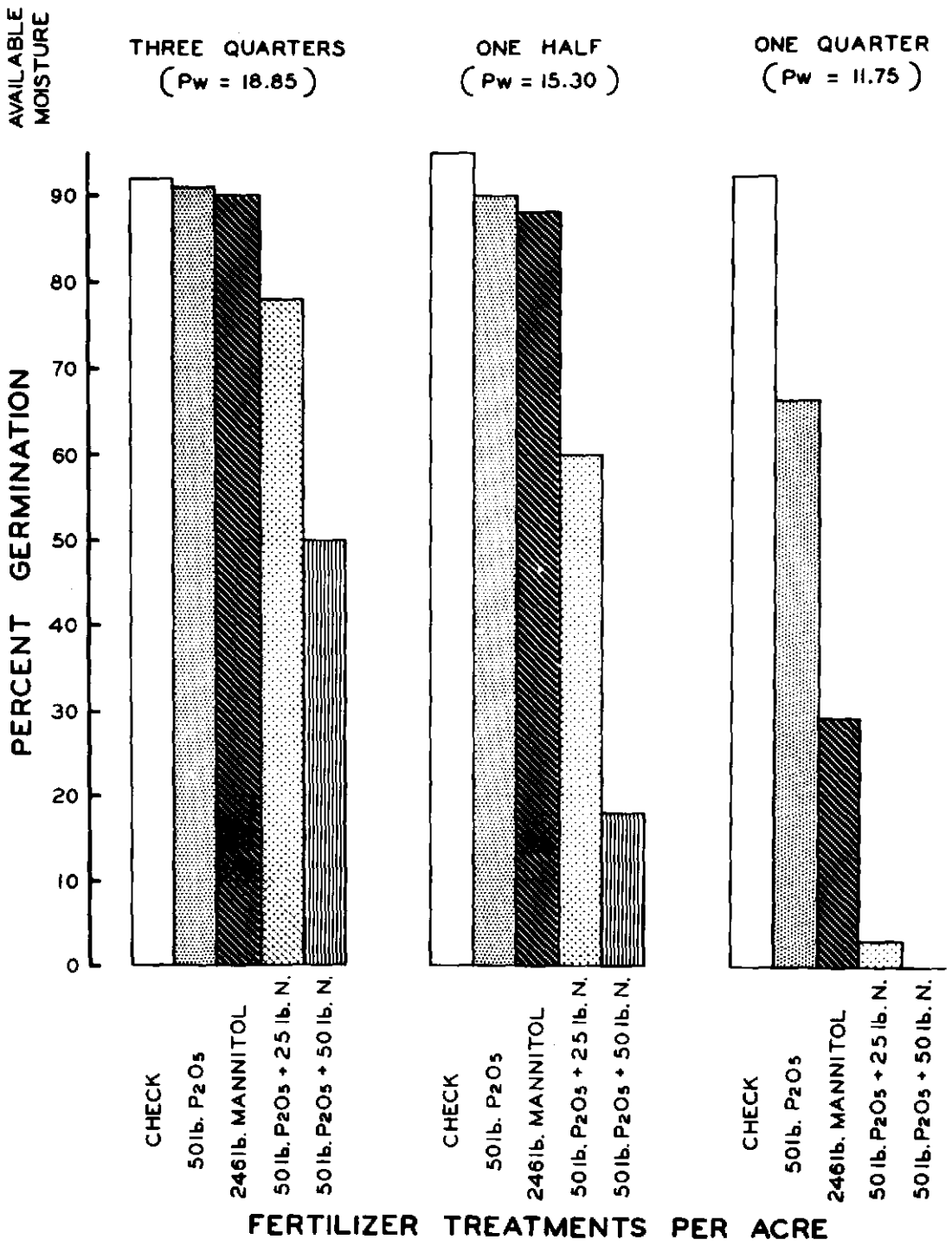

FIGURE 5. GERMINATION OF CANNING CORN AT LETHBRIDGE, 1957.

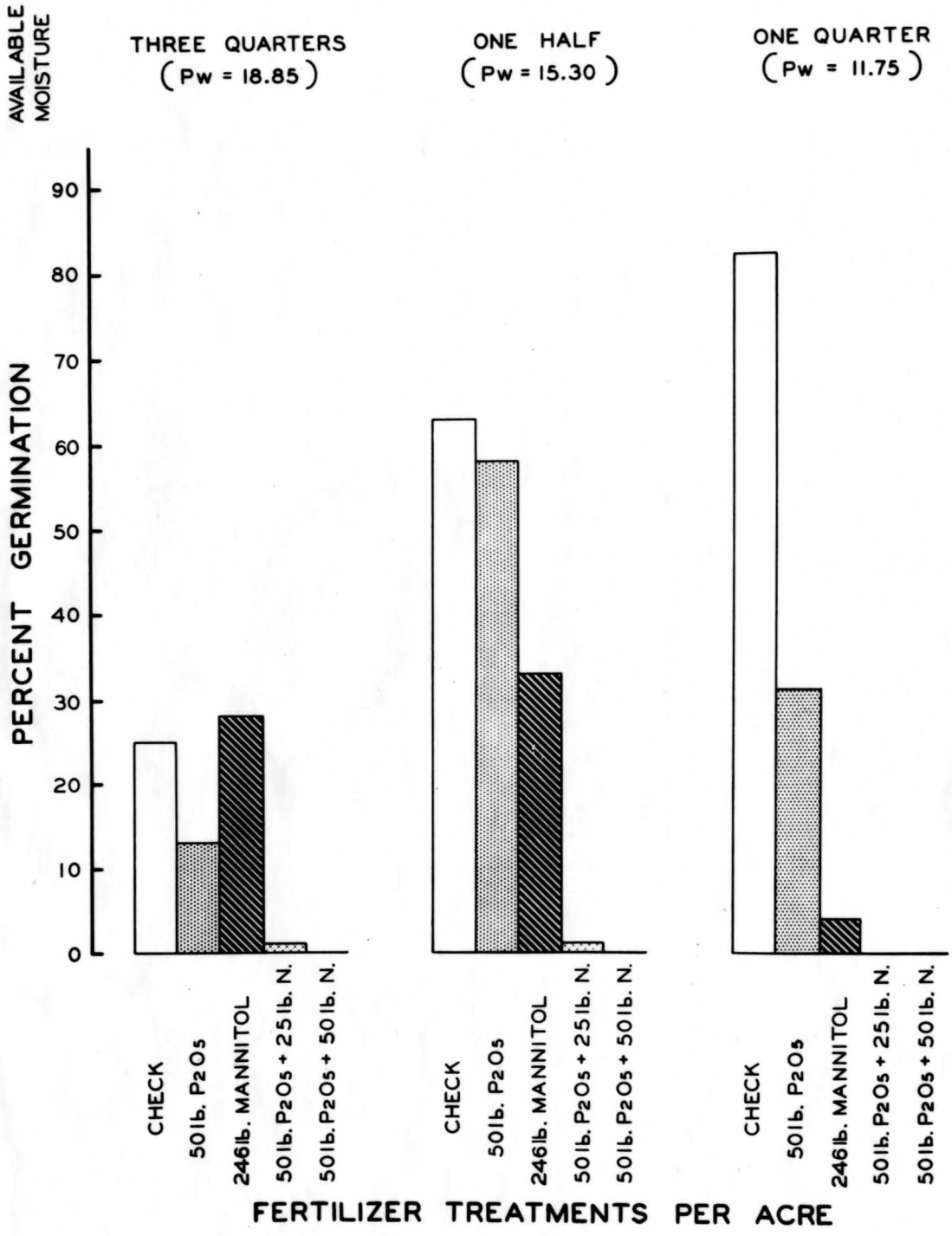

FIGURE 6. GERMINATION OF FIELD BEANS AT LETHBRIDGE, 1957.

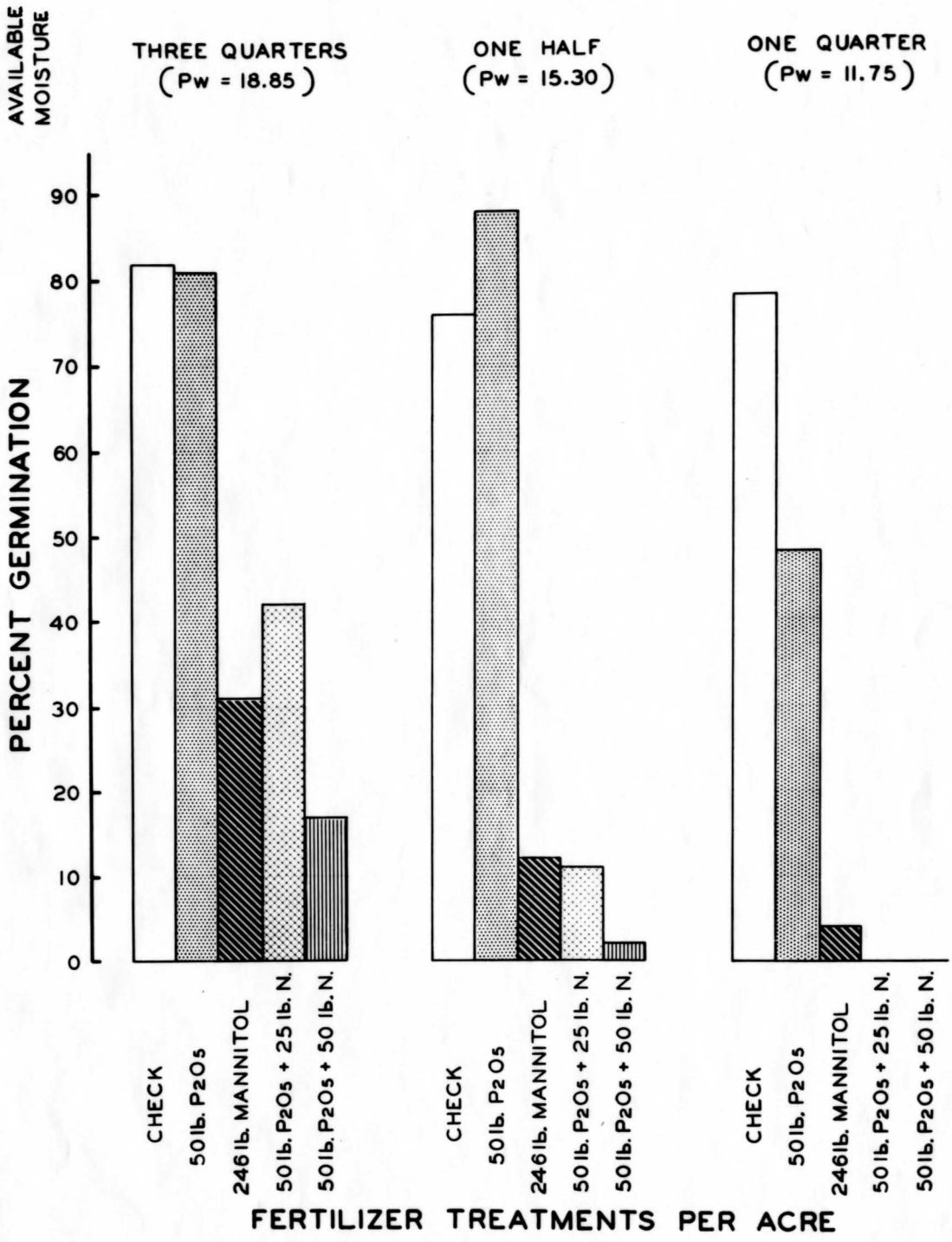

FIGURE 7. GERMINATION OF SUGAR BEETS AT LETHBRIDGE, 1957.

Table 1. Mean percentage germination and significant differences* between treatment means of canning corn, at three soil moisture levels, Lethbridge, Alberta, 1957

Moisture level (Pw)	Fertilizer treatment (pounds per acre)				
	50 P_2O_5 + 50 N	50 P_2O_5 + 25 N	246 Mannitol	50 P_2O_5	Check
18.85	50	78	90	91	92
15.30	18	60	88	90	95
11.75	0	1	29	66	92

* Any two means underscored by the same line are not significantly different.

Table 2. Mean percentage germination and significant differences* where applicable between treatment means of field beans, at three soil moisture levels, Lethbridge, Alberta, 1957

Moisture level (Pw)	Fertilizer treatment (pounds per acre)				
	50 P_2O_5 + 50 N	50 P_2O_5 + 25 N	246 Mannitol	50 P_2O_5	Check
18.85	0	1	28	13	25
15.30	0	1	33	58	63
11.75	0	0	4	31	82

* Any two means underscored by the same line are not significantly different.

Table 3. Mean percentage germination and significant differences* between treatment means of sugar beets, at three soil moisture levels, Lethbridge, Alberta, 1957

Moisture level (Pw)	Fertilizer treatment (pounds per acre)				
	50 P_2O_5 + 50 N	246 Mannitol	50 P_2O_5 + 25 N	50 P_2O_5	Check
18.85	17	31	42	81	82
	50 P_2O_5 + 50 N	50 P_2O_5 + 25 N	246 Mannitol	Check	50 P_2O_5
15.30	2	11	12	76	88
	50 P_2O_5 + 50 N	50 P_2O_5 + 25 N	246 Mannitol	50 P_2O_5	Check
11.75	0	0	4	48	78

* Any two means underscored by the same line are not significantly different.

25 pounds of nitrogen per acre.

When there was approximately one-quarter of the available moisture in the soil (Pw = 11.75), the germination of corn was almost completely retarded with 25 lb. N, and with 50 lb. N there was no germination. Even at this low moisture content, 50 lb. P_2O_5 did not significantly reduce the germination of corn.

At the two higher moisture levels mannitol did not significantly retard germination, while at the lowest moisture level the germination from the mannitol treatment was significantly lower than that from the check.

Figures 8 and 9 provide visual illustration of the germination of corn under the various fertilizer treatments at the 18.85 per cent moisture level. The picture depicted in Figure 8 was taken 7 days after planting. Good emergence of corn is evidenced on the check and the 50 lb. P_2O_5 treatments. The seedlings were just beginning to emerge on the mannitol and the 50 lb. P_2O_5 plus 25 lb. N treatments. All the emerged plants were counted and carefully removed, and the tray was resealed with plastic. Figure 9 shows the subsequent emergence 11 days after planting. Practically all the viable seeds in the check treatment had emerged by the seventh day, and delayed germination in the other treatments is shown. Generally, half of the seedlings on the mannitol treatment were delayed in emerging by 4 or more days. Where 25 lb. N was used, most of the emergence was delayed by at least 4 days. Eleven days after planting, very few seedlings could be seen on the 50 lb. P_2O_5 plus 50 lb. N treat-

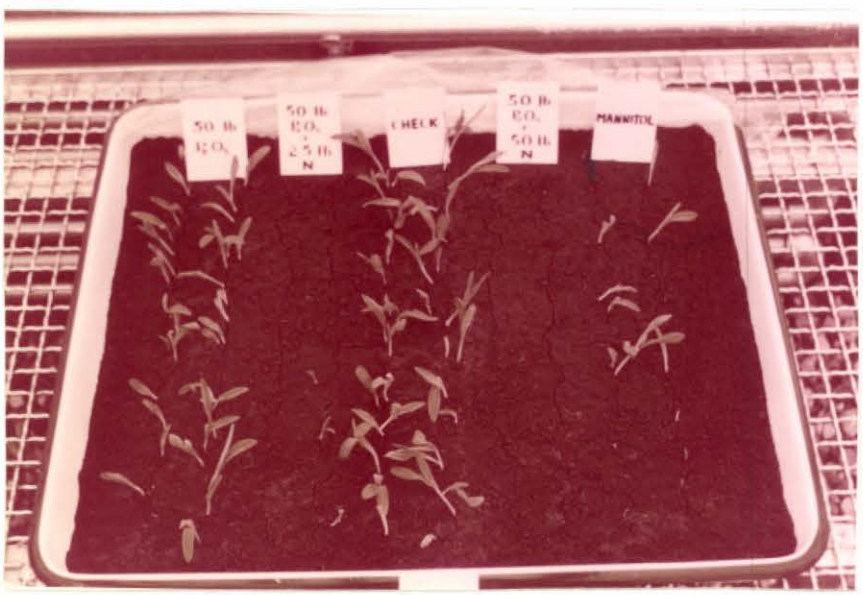

Figure 8. Germination of canning corn, under various fertilizer treatments, seven days after planting, Lethbridge, Alberta, 1957

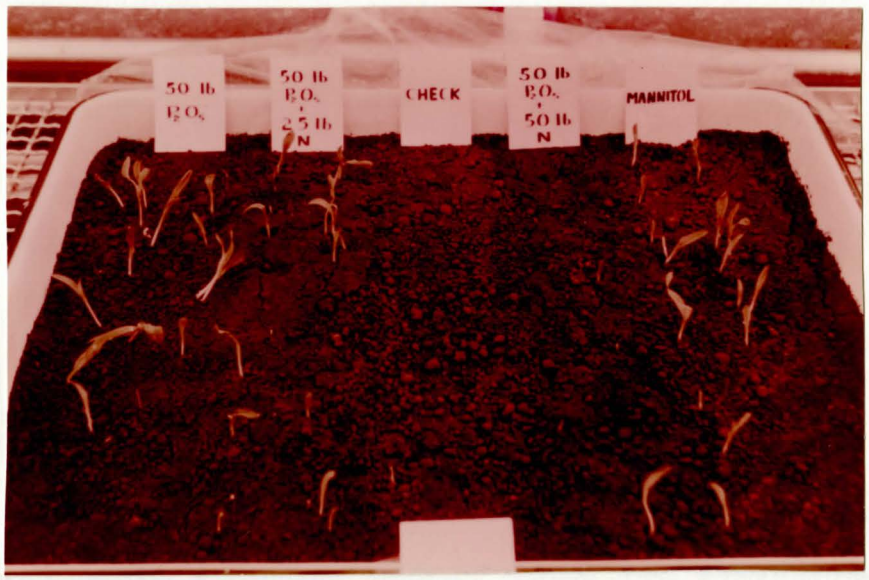

Figure 9. Germination of canning corn, under various fertilizer treatments, eleven days after planting, Lethbridge, Alberta, 1957. On the seventh day (Figure 8) the emerged seedlings were counted and removed.

ment. More than half of the seedlings that emerged from this treatment were delayed by 10 days.

Field beans. At the highest moisture level there were no significant differences in the percentages of germination of field beans between fertilizer treatments. Figure 6 shows the low germination at this moisture level on all the treatments including the check. Figure 6 also shows that germination on the check was progressively higher with decreasing soil moisture.

Where half of the soil moisture was available for plant growth, the germination on the check was significantly higher than on the mannitol treatment but was not significantly different from the 50 lb. P_2O_5 treatment. At the two lowest moisture levels germination on the 50 lb. P_2O_5 treatment was significantly higher than on the mannitol treatment. At the lowest moisture level germination on the check was significantly higher than that on the 50 lb. P_2O_5 treatment.

At all three moisture levels there was essentially no germination of beans on the two treatments that included nitrogen fertilizer.

Figure 10 shows the comparable germination of beans at the three moisture levels 11 days after planting. Beans germinating on the mannitol treatment were observed to have poor root development as shown in Figure 11.

Sugar beets. The germination of sugar beets (Table 3) was significantly higher on the check than on the other treatments at the lowest moisture level. At the highest moisture level germination on the 50 lb. P_2O_5 treatment was

Figure 10. Comparable germination of field beans, eleven days after planting, at three soil moisture levels, Lethbridge, Alberta, 1957

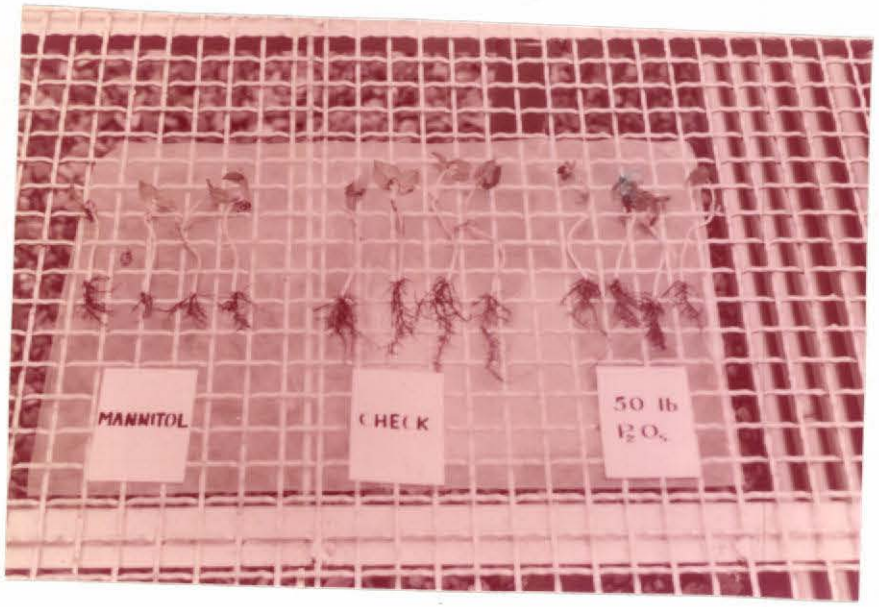

Figure 11. Root development of germinated bean seeds under different fertilizer treatments, Lethbridge, Alberta, 1957

significantly higher than that on the mannitol and the two nitrogen treatments. However, there was no significant difference in germination between the latter three treatments. Germination on the 50 lb. P_2O_5 treatment was significantly higher than on the check at the 15.30 per cent soil moisture level.

Freezing point depression determinations of soils. Because consistent results could not be obtained, particularly at the lower soil moisture levels, no data on this phase of the experiment are presented.

Studies in the germination cabinet

This phase of the study was concerned with germination at iso-osmotic concentrations of ammonium nitrate and mannitol solutions. Of the three crops studied, results were obtained for sugar beets only. The method evidently was not suitable for beans and corn as a large proportion of seeds from these two crops rotted during the germination period.

Statistical analysis of the sugar beet data revealed that there was no significant difference between the two treatment means of ammonium nitrate and mannitol. However, there were highly significant differences between the means for osmotic pressure levels and for the treatment x level interaction. Table 4 shows the mean percentages of germination at the different osmotic pressures and the statistical significance between them, while corresponding information for the treatment x level interaction appears in Table 5.

Table 4. Mean percentage germination of sugar beets at various osmotic pressure levels and significant differences* between them, Lethbridge, Alberta, 1957

Osmotic pressure levels in atmospheres				
10	8	6	2	4
14	42	70	84	85

* Any two means underscored by the same line are not significantly different.

Table 5. Mean percentage germination of sugar beets at various treatments x levels and significant differences* between them, Lethbridge, Alberta, 1957

Treatments x levels									
Ammonium nitrate 10 atmospheres	Mannitol 10 atmospheres	Ammonium nitrate 8 atmospheres	Mannitol 8 atmospheres	Mannitol 6 atmospheres	Ammonium nitrate 6 atmospheres	Ammonium nitrate 2 atmospheres	Ammonium nitrate 4 atmospheres	Mannitol 4 atmospheres	Mannitol 2 atmospheres
2	25	37	46	69	72	82	85	85	86

* Any two means underscored by the same line are not significantly different.

From Table 4 it is evident that, at the one per cent level of significance, the germination of sugar beets was not significantly different at osmotic pressures of 2, 4, and 6 atmospheres. At 8 atmospheres germination was significantly lower than at the three lower osmotic pressure levels but significantly higher than the germination at 10 atmospheres.

The percentage of germination of sugar beets at 10 atmospheres of ammonium nitrate solution was significantly lower than the germination from any of the other level x treatment interaction combinations. There were no significant differences between percentages of germination from solutions of mannitol at 8 and 10 atmospheres, and ammonium nitrate at 8 atmospheres. The percentages of germination from the above three combinations were significantly lower than those from either of the two solutions at 2, 4, and 6 atmospheres.

The average lengths of primary roots of the germinated seedlings are shown in Table 6. From this it can be seen that the roots were progressively shorter with increasing concentration and that they were longer in the mannitol than in the ammonium nitrate solutions.

Table 6. Length, in millimeters, of primary roots of sugar beet seedlings germinated in solutions of various osmotic pressures, Lethbridge, Alberta, 1957

Solution	Osmotic pressure in atmospheres				
	2	4	6	8	10
Ammonium nitrate	18	18	13	7	2
Mannitol	35	35	18	10	10

DISCUSSION

Germination studies in the greenhouse

Canning corn. Of the three crops used in the experiment, the germination of canning corn was least affected by the fertilizer treatments. Where the fertilizer was used, the germination was unaffected by moisture. In farming practice less consideration with regard to soil moisture and fertilizer placement would be required in the planting of corn than in the planting of sugar beets or beans.

Fifty pounds of P_2O_5 did not affect germination at the two highest moisture levels. When soil moisture was limited to one-quarter of the available amount, the phosphorus treatment reduced germination by 26 per cent. Twenty-five pounds of nitrogen, together with 50 pounds of P_2O_5, reduced germination 14 per cent at the three-quarter moisture level and 35 per cent at the one-half moisture level, and almost entirely retarded germination at the one-quarter level. An additional 25 pounds of nitrogen resulted in further reductions in germination.

If a germination reduction of 40 per cent is arbitrarily considered to be of economic significance in terms of final stand of plants and eventual yield, it would be unwise to use 50 pounds of soluble nitrogen for canning corn, regardless of the soil moisture status. With less than one-half of the available moisture in the soil, 25 pounds of nitrogen applied with the seed at planting time

can seriously reduce the germination of canning corn. The present recommendation in Alberta of 150 pounds of 16-20-0 fertilizer could result in reduced germination if soil moisture were limiting and if the fertilizer were placed in close contact with the seed.

The mannitol treatment did not affect germination to the same extent as either of the two nitrogen treatments, although it was at the same molal concentration as the lower nitrogen treatment. Generally, the results with mannitol were similar for all three crops. There may be two reasons why mannitol behaved differently from the nitrogen treatment. The first is that ammonium nitrate is more soluble and in solution dissociates into two ions, so that the osmotic effect of ammonium nitrate was more pronounced than that of mannitol. The other reason is that the ammonium or nitrate ions may have been toxic to the germinating seedlings. Because it was impossible to carry out the freezing point depression determinations, there was no way of assessing the extent of solution of the fertilizer treatments.

Field beans. Field beans were the most sensitive crop to both moisture and fertilizers. Under the conditions of this experiment, relatively high soil moisture conditions were not favourable to the germination of beans. It was not determined whether it was the high moisture alone that caused the beans to rot, or the combination of moisture, consistent high temperature, and limited aeration. Undoubtedly, the high humidity in the covered trays was conducive to fungus growth, and, although the seeds were

treated, the micro-organisms in the soil could enter the ruptured seed coat during the early stages of germination.

Because the germination of beans was very low at the three-quarter moisture level, no significant difference was established between fertilizer treatments. Germination of beans on the two nitrogen treatments was almost completely retarded at all three moisture levels. Highly-soluble fertilizers, therefore, should not be used for beans if the placement is with the seed, regardless of the soil moisture status. If soil moisture is limiting, the less-soluble fertilizers, such as 0-46-0, should not be placed directly with bean seeds. Generally, it would be wise not to place any type of fertilizer in contact with bean seeds.

Sugar beets. Sugar beets were similar to canning corn in that the germination was relatively unaffected by moisture when no fertilizer was used. The nitrogen treatments retarded sugar beet germination more than they did the germination of corn, but not to the extent that field bean germination was affected.

If half or more of the available soil moisture is in the soil, 50 pounds of P_2O_5 could be used safely for sugar beets. Even with one-quarter of the available moisture in the soil, approximately one-half of the seeds germinated on the phosphorus treatment. Since sugar beets are thinned to one plant per foot within the row, such a reduction is not necessarily serious. The practice in southern Alberta of applying 100 pounds of 11-48-0 fertilizer with the seed at planting time is fairly sound. Fertilizers that are more

soluble than 11-48-0, such as 16-20-0, could seriously retard the germination of sugar beets, especially if the rate of application were more than 100 pounds per acre.

The germination study in the greenhouse was conducted under fairly constant soil moisture conditions, and the above discussions would apply only during years when subsequent to planting there is no rainfall for a considerable period of time. Under field conditions, precipitation could suddenly change the moisture status of the soil and, in turn, the germination of seeds. The author observed that, where seeds had failed to germinate for two weeks in a dry soil, subsequent watering resulted in substantial germination of the same seeds.

This study was concerned with only one fertilizer placement, that is, the fertilizer was placed in approximately direct contact with the seed. Undoubtedly, the retarding effect of some of the fertilizer treatments would not have been so severe if the fertilizer had been placed some distance away from the seed.

Studies in the germination cabinet

The germination of sugar beets was unaffected by osmotic pressures of up to 4 atmospheres. A non-significant reduction was observed at 6 atmospheres. At osmotic pressures over 6 atmospheres the germination of sugar beets was significantly reduced. The critical tolerance for sugar beets of osmotic pressure, soil moisture tension, or total soil moisture stress would thus appear to be somewhere between 6 and 8 atmospheres.

At osmotic pressures of 2, 4, or 6 atmospheres there were no significant differences in the percentages of germination between an organic and an inorganic solution. As the osmotic pressure was increased, germination was lower in the inorganic solution until at 10 atmospheres it was significantly lower than that in the organic solution.

It would appear that, as moisture becomes less available to sugar beet seeds, germination is retarded by the toxicity of either the nitrate or ammonium ions or both.

SUMMARY

Germination results of canning corn, field beans, and sugar beets at three soil moisture levels and under five fertilizer treatments, along with the results of germination of sugar beets at iso-osmotic concentrations of mannitol and ammonium nitrate solutions, are reported.

The germination of canning corn was least affected by limited soil moisture and soluble fertilizers, while that of field beans was most affected.

Fifty pounds of P_2O_5 did not significantly affect the emergence of corn when between one-quarter to three-quarters of the available moisture was in the soil. The same fertilizer treatment resulted in significantly lower germination of sugar beets and field beans at the lowest moisture level.

With approximately three-quarters of the available moisture in the soil, 50 pounds of soluble nitrogen fertilizer significantly lowered the germination of corn when compared with the germination from the other treatments, viz., check, 50 pounds of P_2O_5, 246 pounds of mannitol, and 25 pounds of soluble nitrogen. At the one-half level of available soil moisture, significant reduction in the germination of corn was observed with 25 pounds of soluble nitrogen.

At the highest moisture level, the germination of beans was very poor under all fertilizer treatments, which could

be attributed to fungus growth.

At all three moisture levels, the germination of field beans was almost completely retarded with 25 pounds of nitrogen.

With only one-quarter of the available moisture in the soil, the nitrogen treatments resulted in virtually no germination of any of the three crops.

Placement of any fertilizer should not be done in contact with bean seeds. The highly-soluble fertilizer, ammonium nitrate, should not be placed in contact with corn or beet seeds when soil moisture is limiting.

Germination of sugar beets was significantly lowered in solutions whose osmotic pressures exceeded 6 atmospheres.

With increasing osmotic pressure at iso-osmotic concentrations, germination of sugar beets was lower in ammonium nitrate solutions than in mannitol solutions, suggesting toxicity of the nitrate or ammonium ions.

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APPENDIX

Table 1a. Standard germination tests carried out on seed samples of the three crops by the Plant Products Division of the Canada Department of Agriculture Production Service, Calgary, Alberta, 1957

	Percentage germination		
	Canning Corn	Field Beans	Sugar Beets
Normal seedlings	85	90	81
Abnormal seedlings	13	4	6
Dead seedlings	2	6	16

Table 2a. The calculation of osmotic pressures from freezing point data from International Critical Tables

			Ammonium nitrate				
Molal conc.	0.01	0.02	0.05	0.1	0.2	0.5	1.0
Δ_{tf}/mole	3.572	3.535	3.470	3.396	3.296	3.11	2.92
Δ_{tf}	0.0357	0.0707	0.1735	0.3396	0.6592	1.555	2.92
O.P. = 12.06 Δ_{tf}	0.4308	0.8526	2.0924	4.0956	7.9499	18.7533	35.2152
			Mannitol				
Molal conc.	0.01	0.02	0.05	0.070	0.10	0.27	0.546
Δ_{tf}/mole	1.854	1.855	1.857	1.858	1.859	1.864	1.866
Δ_{tf}	0.01854	0.03710	0.09285	0.13006	0.1859	0.50496	1.01884
O.P. = 12.06 Δ_{tf}	0.2236	0.4474	1.1198	1.5685	2.2419	6.0898	12.2872

Table 3a. Conversion of molal concentrations to molar using density data* from International Critical Tables

Percent solution	Grams salt per 1,000 grams H_2O	Ammonium nitrate			Mannitol		
		Molality	Grams salt per liter	Molarity	Molality	Grams salt per liter	Molarity
1	10.10	0.1262	10.02	0.1252			
2	20.408	0.2549	20.046	0.2504	0.1120	20.136	0.1105
4	41.666	0.5205	40.588	0.5070	0.2288	40.564	0.2227
6	63.829	0.7974	61.380	0.7668	0.3504	61.272	0.3363
8	86.956	1.0863	82.504	1.0306	0.4773	82.272	0.4516
10	111.111	1.3880	103.970	1.2988	0.6099	103.570	0.5685

* Density data for mannitol determined by author as follows -

Percent solution	2	4	6	8	10
Specific gravity	1.0068	1.0141	1.0212	1.0284	1.0357

Table 4a. Summary of analysis of variance of transformed data of the germination of canning corn

Variance due to	D.F.	Mean squares		
		Pw = 18.85	Pw = 15.30	Pw = 11.75*
Replicates	3	165.25	216.88	61.58
Treatments	4	604.25**	2146.22**	2019.89**
Error	12	49.80	80.17	153.11
Total	19			

* Treatments 50 lb. P_2O_5 plus 25 lb. N and 50 lb. P_2O_5 plus 50 lb. N excluded because results were consistently zero. The degrees of freedom for treatments, therefore, is only 2.

** Significant at the 1% level.

Table 5a. Summary of analysis of variance of transformed data of the germination of field beans

Variance due to	D.F.	Mean squares		
		Pw = 18.85	Pw = 15.30	Pw = 11.75
Replicates	3	1613.09	135.32	117.13
Treatments*	2	94.71	372.38**	3041.50**
Error	6	41.68	13.19	39.88
Total	11			

* Treatments 50 lb. P_2O_5 plus 25 lb. N and 50 lb. P_2O_5 plus 50 lb. N excluded because results were consistently zero at all three moisture levels.
** Significant at the 1% level.

Table 6a. Summary of analysis of variance of transformed data of the germination of sugar beets

Variance due to	D.F.	Mean squares		
		Pw = 18.85	Pw = 15.30	Pw = 11.75*
Replicates	3	533.60	5.72	48.46
Treatments	4	1747.28**	3275.96**	2835.05**
Error	12	90.26	43.12	89.42
Total	19			

* Treatments 50 lb. P_2O_5 plus 25 lb. N and 50 lb. P_2O_5 plus 50 lb. N excluded because results were consistently zero. The degrees of freedom for treatments, therefore, is only 2.

** Significant at the 1% level.

Table 7a. Summary of analysis of variance of transformed data of the germination of sugar beets in solutions

Variance due to	D.F.	Mean squares
Replicates	3	32.65
Treatments	1	401.95
Replicates x treatments (Error 1)	3	45.97
Levels	4	3640.75**
Levels x treatments	4	219.38**
Error 2	24	49.04
Total	39	

** Significant at the 1% level.